FINAL REPORT

DESIGN AND CONSTRUCTION OF A REMOTE SENSING APPARATUS

National Aeronautics and Space Administration
Marshall Space Flight Center

Multidisciplinary Research Grant
NGR-19-001-068

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INTRODUCTION

Identification of man's natural environment by remote sensing has great potential in helping man's continuing search to understand his world and to improve his position in it. In recent years our capabilities in this area have been greatly expanded by improved and new techniques in photography and by the advent of multispectral scanners. With these and possibly new techniques to be discovered, wildlife and plants can be inventoried, mineral and ore deposits discovered, and pollutants identified. These are only a few of the applications which might be named.

Of all the applications to which remote sensing can be applied in man's natural environment, identification of the natural and cultivated vegetation which covers the earth is one of the most difficult as well as potentially useful areas. Also, the solution of any of the general problems or data contributed thereto in this area will most likely be of help throughout the field of remote sensing. Therefore, a general survey was made with particular reference to finding general problems and formulating an overall approach that should be taken if an inventory of all vegetation on the earth were to be made. From this study a number of conclusions were made and a problem area in which research is being undertaken was identified.

First, it was concluded that if identification of vegetation over large areas is to be done by remote sensing, a multispectral type of approach will be required. Sensing of both emitted and reflected thermal radiation will be required over as much of the electromagnetic spectrum as possible. Also, the maximum number of bands as can be obtained with available equipment will probably be required in order to find identifying characteristics for the many types of vegetation. It seems immaterial whether the data is recorded photographically or electronically on magnetic tape as long as the data can be processed and fed into a computer.

A second conclusion that was made was that automatic processing of the data was required. Even without remote sensing satellites, there is a greater ability to collect data than an ability to understand or properly interpret the data. This statement becomes more forceful when the ERTS and Skylabs programs are considered. Obviously if making a general inventory of vegetation on a global scale, automatic processing is imperative.

A problem which arises frequently is a need for ground truth measurements. This need arises from an approach that begins with the development of a technique for doing remote sensing, such as development of the multispectral scanner. Data is then generated. Identification and application centers upon interpretation of the data. This is generally done by taking a lot of ground truth measurements to interpret the remote data readings. A computer program may be used to identify those areas which show the same spectral characteristics as the soils and types of vegetation which have been verified by ground truth. Supposedly, the unverified data readings will show the same general spectral characteristics as the verified or identified data corresponding to the same vegetation or soil type. This approach has led to the identification of various crops and soil types with an accuracy as high as eighty percent. However, the method is very limited because ground truth measurements are required for each crop or soil type to be identified. Also, ground truth measurements must be made with each scan.

Another approach is to define the spectral characteristics of natural objects in their natural environment in great deal and the variation of these characteristics with changes in the natural environment. This information could lead to particular identifying patterns for each type of soil or vegetation for which identification is required. Techniques for collecting spectral data in the region required would be developed. The data could then be processed by a computer. This approach has its limitations in that a great deal of spectral information is required. Also, the standards data must be taken in a natural environment and not a laboratory, and the variation of the spectral characteristics with the natural variables must be known. The advantage of this approach is that ground truth verification is no longer needed for identification.

In any general approach to identifying vegetation, ground truth measurements must be held to a minimum. For a global survey from a satellite, ground truth for calibration purposes and spot checks are all the ground truth measurements that are feasible. This will require knowing the identifying patters for the vegetation to be inventoried and the effects of all natural variables on these identifying patterns. Therefore, the effects of the natural environment on the energy emitted and reflected from vegetation must be determined if any type of meaningful identification of vegetation over a large area by remote sensing is to be achieved.

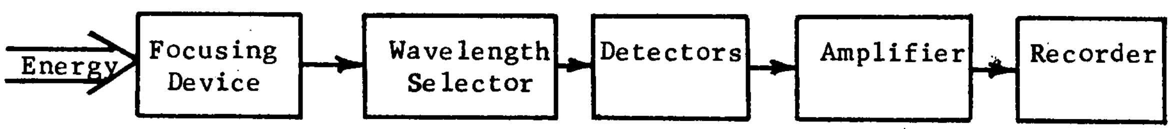
The natural environment as it affects the energy outgoing from vegetation is composed of many variables. These include sun angle, angle of reflectance, plant spacing, soil type, terrain features, moisture content in soil, humidity, temperature, wind velocity and shadows. The problem immediately arises: how do we study these things in a laboratory? Generally, we cannot, so why not take the laboratory to the environment. This requires setting up a laboratory outdoors which can continuously monitor by remote sensing a particular type of vegetation through a cycle of changes in the environment, including seasonal changes. Even though this seems like a rather difficult task, it was decided that an experiment would be undertaken to add to the present knowledge in this area.

In general, if more information were known about the effects of natural variables on data received by remote sensing, less ground truth measurements would be needed since the effects of some of the variables would be reduced to mathematical formulas or data tables and stored in the computer to be used in the automatic identification procedure. This would greatly help techniques for data reduction in all applications of remote sensing.

DESIGN

The objective of the research was defined as a study of the effects of natural variables, in particular sun angle, reading angle, resolution, moisture content of the soil, and atmospheric conditions, on the reflective and emittive properties of vegetation. Since these natural variables, and not a specific species of plant life, were the objective of the study, the area over which the experiment takes place was reduced to minor importance and was not included as a part of the design criteria. The major design criteria involved measurements of a natural environment over long periods of time and the monitoring of all the energy from several square feet of area.

Two techniques were discussed as feasible. Both techniques included the use of a radiometer, as shown in the schematic below, for monitoring the electromagnetic energy being emitted and reflected.

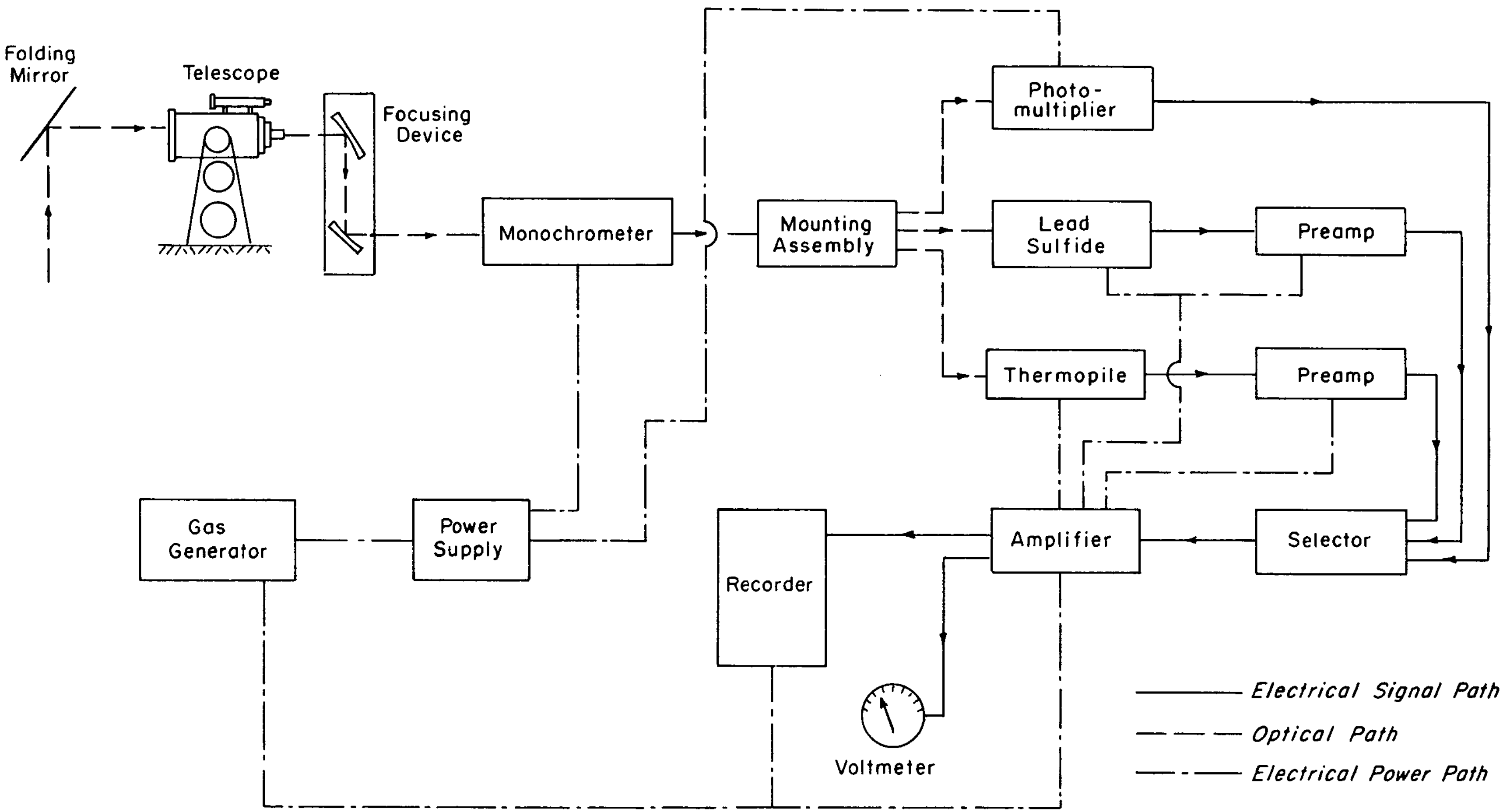


The wavelength selector would be a variable device so that energy from the ultraviolet to the far infrared region could be monitored. One technique involved mounting the radiometer on a tower looking down on the area to be monitored. The other idea was to keep the radiometer on the ground and to carry a large mirror aloof on a balloon system. The mirror would be used to focus the energy from the control plot of vegetation back to the radiometer to be monitored.

Because of the cost and lack of mobility of a platform, the balloon system was given first consideration. The main problem concerning a balloon system was its stability. Therefore, a study was made in this area. A review of the study is given in the following section of this report. From this study it was concluded that a balloon system was feasible; therefore, the design of the equipment for the experiment was made assuming that the radiometer would be kept on the ground. The fact that a balloon system allowed more versatility was a positive factor in making this decision; the apparatus would not be limited to exclusive direct monitoring on the ground around a platform, and the reading angle (the angle at which energy is received from the vegetation) could be easily varied as a result of this versatility.

A mobile radiometer was then designed as shown in Figure 1. The device was called a Mobile Remote Sensing Laboratory (MRSL). Since the MRSL was to be used outside and had to be transported, it was decided to build it so that it could all be carried on a truck bed. The first problem dealt with was the fact that the optical system had to be aligned at all times, whereas the viewing angle could vary. This meant that the entire optical system had to be mounted on a platform with three-dimensional freedom. Since the device was to be used outside and had to be movable, a portable electric generator was required for electrical power. In the radiometer design, several detectors were required since energy measurements were to be made over a large portion of the electromagnetic spectrum.

With the MRSL the spectral characteristic of reflectance and emittance can be recorded from a natural scene in a manner similar to remote sensing as done from an aircraft or satellite. However,



SCHEMATIC OF MOBILE REMOTE SENSING LABORATORY

FIG. 1

unlike an airborne system, the MRSL can continuously monitor a fixed portion of the natural environment. Ground truth measurements can be recorded at the same time. Once enough data is collected, the effects of variations in the natural environment on the energy radiated from vegetation will be determined and correlation factors calculated.

Mechanical Design

The mechanical design of the MRSL consisted mostly of designing a mounting platform for the optical train. The platform was required to have three degrees of freedom. A photograph of the resulting design is shown in Figure 2. Most of the optical train is shown mounted in position.

The majority of the weight of the platform is in the base plates which are easily disassembled; therefore, the entire assembly can be broken down into parts that can be carried by two men and reassembled. This design allows the optical train to be assembled, aligned, and checked out indoors on the platform. Then the mounting platform can be disassembled while leaving the optical train intact. The entire MRSL can then be reassembled on the bed of a truck and carried to the test site. Measurements will be made with the MRSL from the truck. With only minor modification the mounting platform could be mounted on a tower and used to monitor vegetation directly if the scheme for a balloon-held mirror proves impractical.

The mounting platform includes locking devices for holding the telescope and optical train in any position desired. The design also includes a method for obtaining fine adjustments.

Other mechanical portions of the MRSL were designed. These

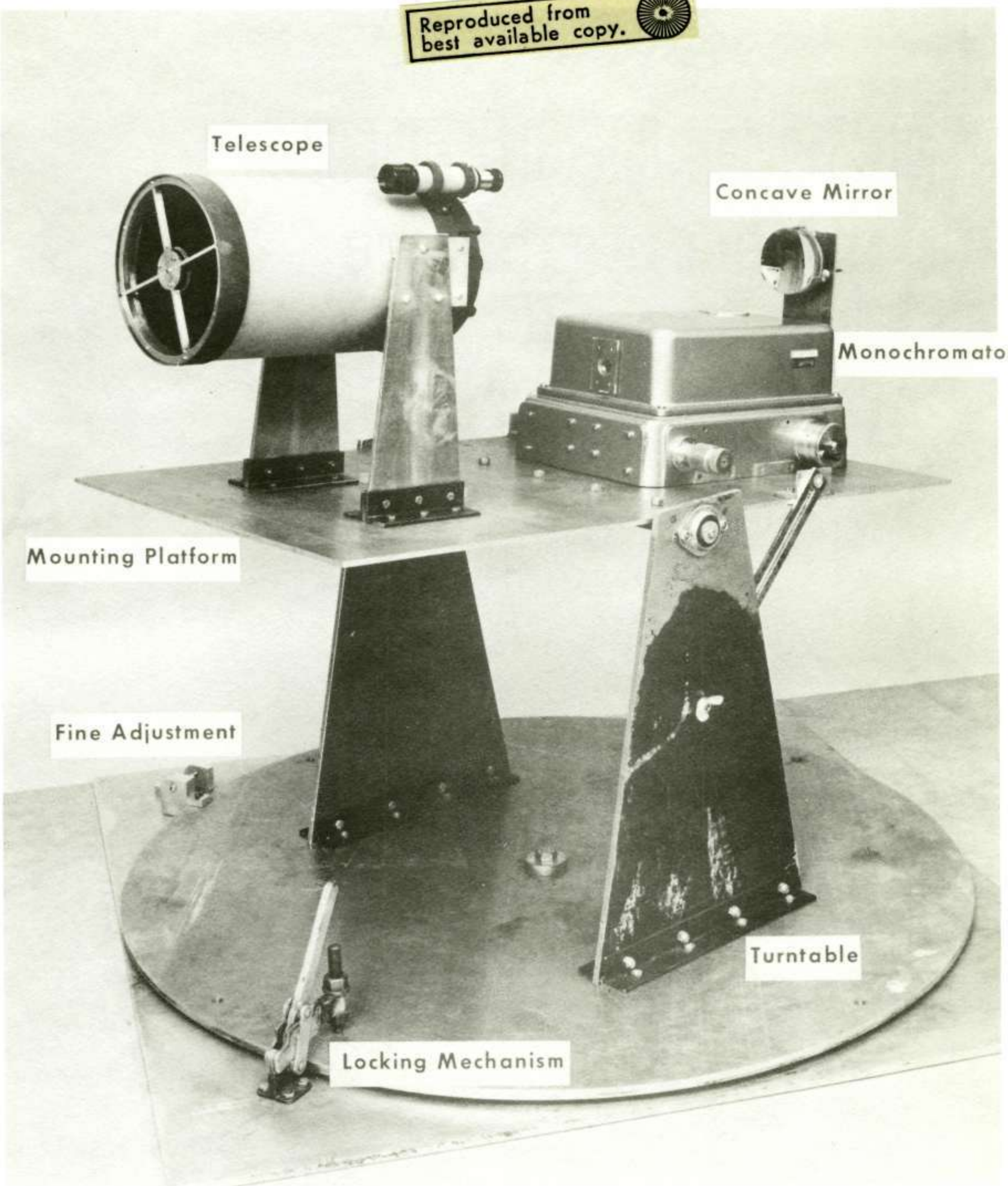


Figure 2. Photograph of Mounting Platform

include the mounting arms for the telescope and light-tight boxes for mounting concave and convex mirrors which transfer the light from the telescope to the monochromator. Another item which was designed and built exclusively for this experiment was a secondary mirror mount for the Celestron 8 telescope. The telescope was of the Schmidt-Cassegrain configuration. The secondary mirror was held in place by a corrector lens that was made of ordinary crown glass. In order to make measurements in the infrared region, the corrector lens had to be removed. This meant that a new mounting system was required for the secondary mirror. A photograph of the mirror and mount is shown in Figure 3.

Optical Design

The heart of the MRSL design is the optical system. The objective of the optical system is to focus the energy being received and to select the wavelength of the energy which is to be converted into an electrical signal by a detector.

The optical train of the MRSL operates as follows. Energy, some in the form of light, is radiated in all directions from a plot of vegetation. A portion of this energy impinges on the folding mirror which is held aloof by a balloon system. This energy is then reflected back to the ground where it is received by a Celestron 8 telescope. The Celestron 8 telescope is an 8-inch telescope of the Cassegrain configuration. Therefore, the energy impinges on the primary mirror, is reflected to the secondary mirror and then focused through the telescope exit. The lenses of the telescope have been replaced by mirrors which focus the energy received by the telescope to a monochromator. The lenses of the original telescope have been replaced so that infrared

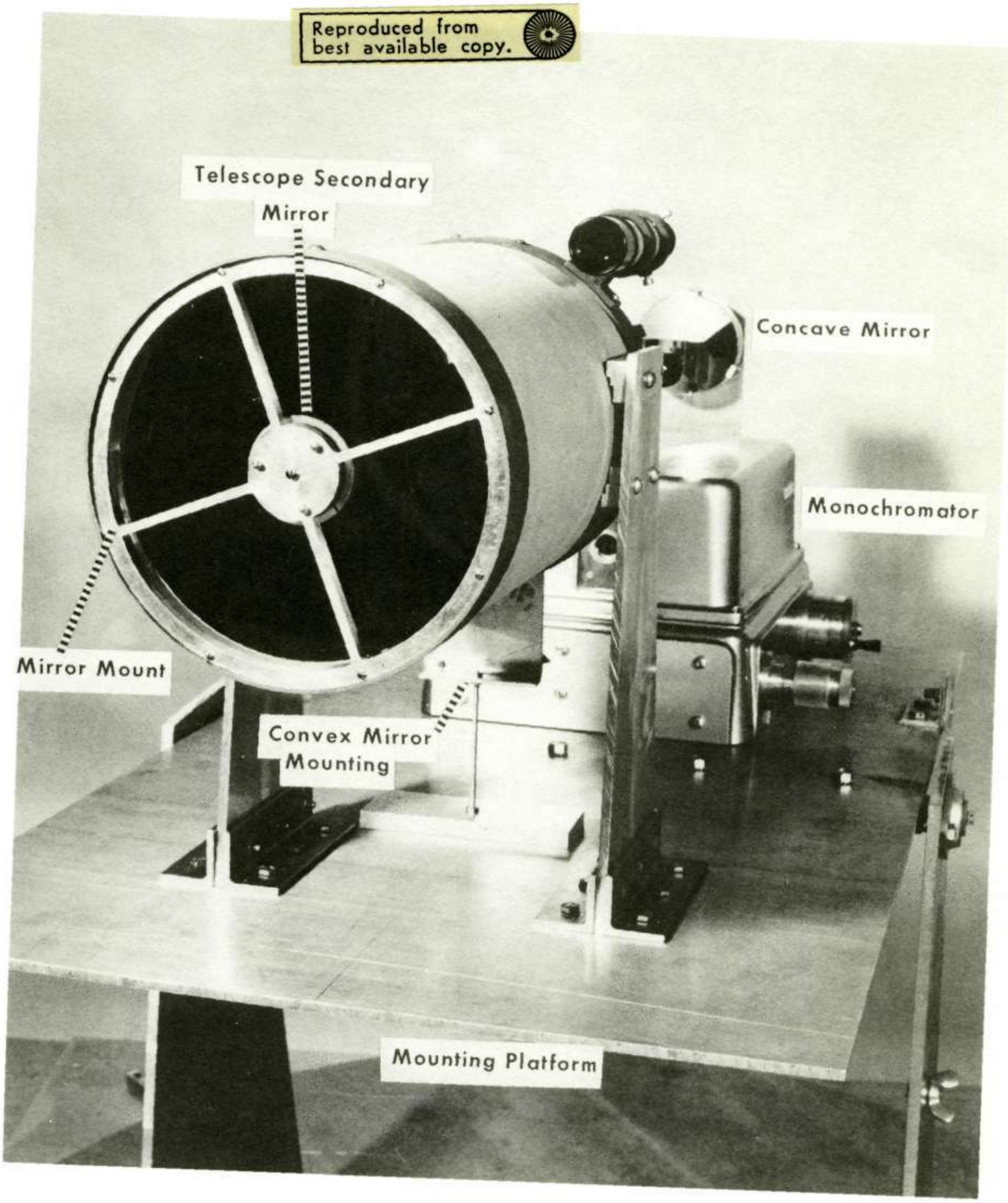


Figure 3. Photograph of Secondary Mirror Mount

radiation can be transmitted as well as change the focusing characteristics of the telescope.

The monochromator selects manually the wavelength of electromagnetic energy which is allowed to pass to the detectors. The monochromator on the MRSL is the Perkin-Elmer Model 99. It is designed to provide monochromatic radiation with high spectral purity. All the optics except the prism are reflecting; therefore, two prisms must be used whenever energy measurements are needed in the infrared region. For these experiments a fused silica prism will be used for wavelengths from 0.2-2.7 microns and a NaCl prism will be used for wavelengths from 2.0-15 microns.

Accessory devices to the monochromator are used to mount the detectors at the exit of the monochromator and to focus the energy properly. Again two devices are required: one device is for mounting the photomultiplier tube which is used in the ultraviolet and visible portions of the spectrum; the other device is used for mounting the lead sulfide and thermopile detectors. Like the prisms, only one detector can be used at a time so that with any given configuration of the equipment only a limited wavelength range can be investigated. However, the total range of the equipment as designed will go from 0.2 microns to 15 microns.

Electrical Design

The electrical design consists of three detectors which convert electromagnetic energy into an electrical signal, amplifiers, recorders, and their support equipment. Three detectors were needed to cover the wavelength range in which measurements were made.

A RCA 1P28 photomultiplier tube was used in the range of 0.2μ to 0.7μ. The tube is a nine-stage side-on type with an S-5 spectral response. Power was supplied at a regulated voltage of 1000 volts D.C. from a Fluke Model 3013 D.C. power supply to the photomultiplier tube.

A lead sulfide detector was used in the spectral range of 0.7μ to 2.0μ. The cell was an Optoelectronic KH2-12 with a 10 x 10 mm sensitive area and a resistance of 220K ohms. The cell was simply connected to the thermocouple pre-amplifier (Perkin-Elmer Model 112-0028) for the input and output connections.

In the spectral range of 2.0μ to 15μ a thermocouple detector (Charles M. Reedes Model NSL-7C) was employed. This thermocouple has a resistance of 30 ohms and a sensitive area of 8 x 8 mm with a KBr window. With this type window material, the detector cannot be operated where the relative humidity is above 40 percent; a small heater is used to accomplish this purpose. The output of the thermocouple was connected to a pre-amplifier (Perkin-Elmer Model 088-0054) and then to an amplifier (Perkin-Elmer Model 107).

The lead sulfide pre-amplifier (Perkin-Elmer Model 112-0028) has a gain of 100 at 13 cycles per second. It also contains a device for switching electronically between the output of the three detectors and is rack mounted.

The thermocouple pre-amplifier (Perkin-Elmer Model 088-0054) has an overall gain of 6000. It is a single stage, 13 cycle per second amplifier with 10 ohm input independence. The required load resistance and power is supplied by the Model 107 amplifier.

The amplifier (Perkin-Elmer Model 107) is for 19-inch rack mounting. It is a three-stage, 13 cycle per second carrier amplifier; maximum gain is 750, and it is controlled by a step alternator of 4 DB per step and a potentiometer.

Most of the electronic gear was mounted on a 19 inch rack for ease in moving. A photograph of this rack and equipment is shown in Figure 4. This recorder is a Leads and Northrup two-speed "Speedomat" single channel recorder. The digital voltmeter was not mounted at the time of the photograph but is a Fluke Model 8000A.

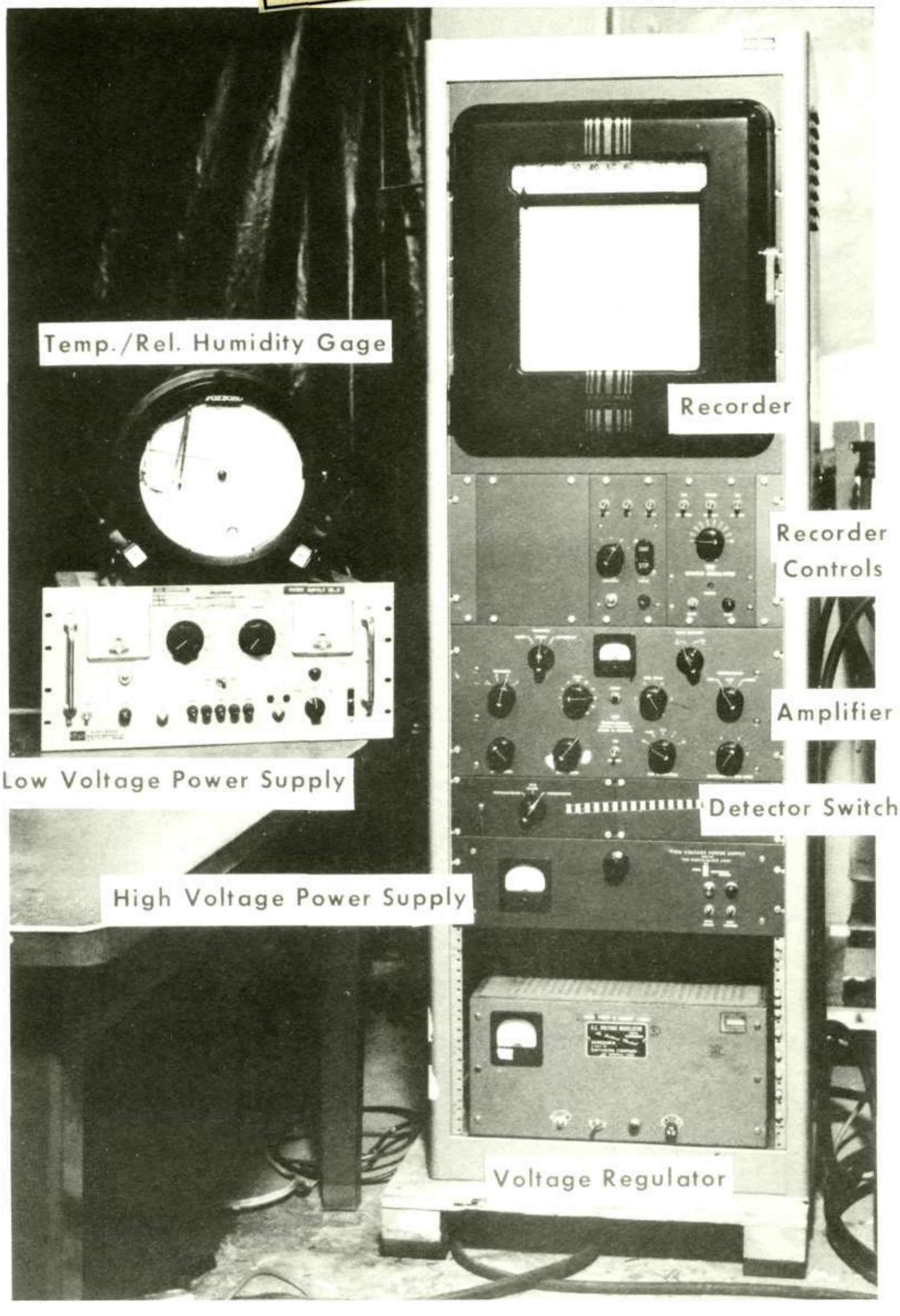


Figure 4. Photograph of Electronics Rack

BALLOON AS A STABLE PLATFORM

Balloon Design

Once it was decided that a balloon system supporting a mirror would be the least costly and most versatile approach for the experiment, a study was made to determine if a balloon system would have the required stability. The study was made from a design rather than an analysis standpoint; that is, a balloon system was designed to the specifications of the experiment. Using this approach, better stability could be achieved (if it were required) by building our own balloon system. The following initial design specifications were given:

(1) Movable to any altitude up to 300 feet,

(2) Minimize vertical, lateral and angular excursions,

(3) Operational in winds up to 20 knots.

The first design aspect of the balloon study was shape. Since the factor of main importance for the experiment was stability, an aerodynamic shape was all that was considered. This type of balloon has better flow characteristics and if flown at a slight angle of attack will generate added lift from the wind. The optimum airship shape will have a fineness ratio of approximately 4.0. Therefore, the NACA 0024 symmetrical airfoil (Figure 5) with a circular cross section was chosen. The fineness ratio of this shape is 4.17. However, the end must be rounded as shown in the Figure which reduces the fineness ratio to a value of 3.75.

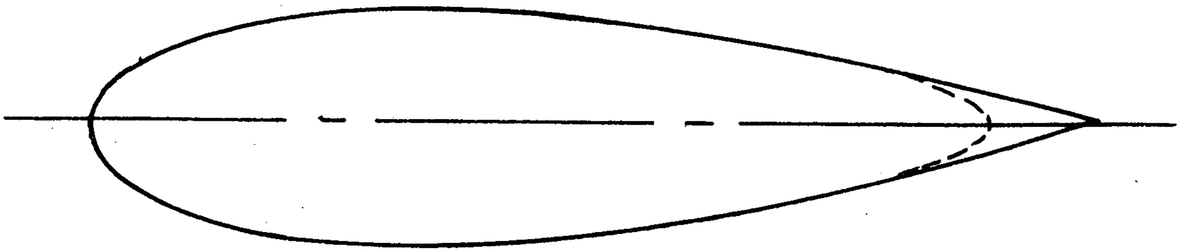


Figure 5

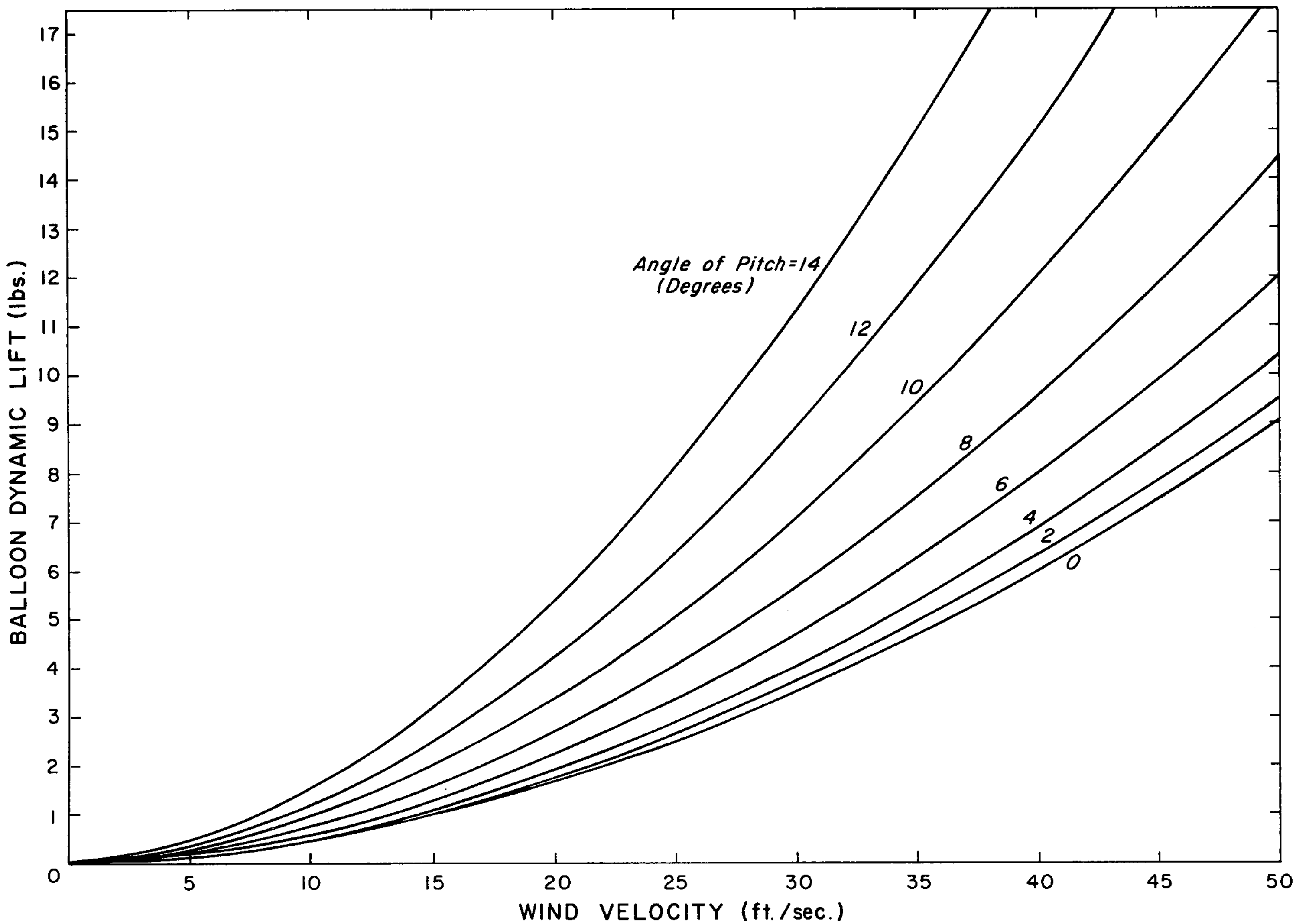
NACA 0024 Airfoil

Helium was chosen as the lifting gas rather than hydrogen. Hydrogen does have a slight advantage in lifting power (0.707 lbs/ft^3 for hydrogen as compared to 0.649 lbs/ft^3 for helium), but it is not enough to overcome the safety factor.

The payload of the balloon was estimated to be ten pounds. Based on this, a volume of 1000 cubic feet was used is sizing the balloon. 1000 cubic feet of helium has a total lifting capability of 57 pounds in hot air. The balloon has a length of 31 feet, a maximum diameter of 8.25 feet, and a surface area of 570 square feet. The material selected for building the balloon was nylon/Mylar laminate.

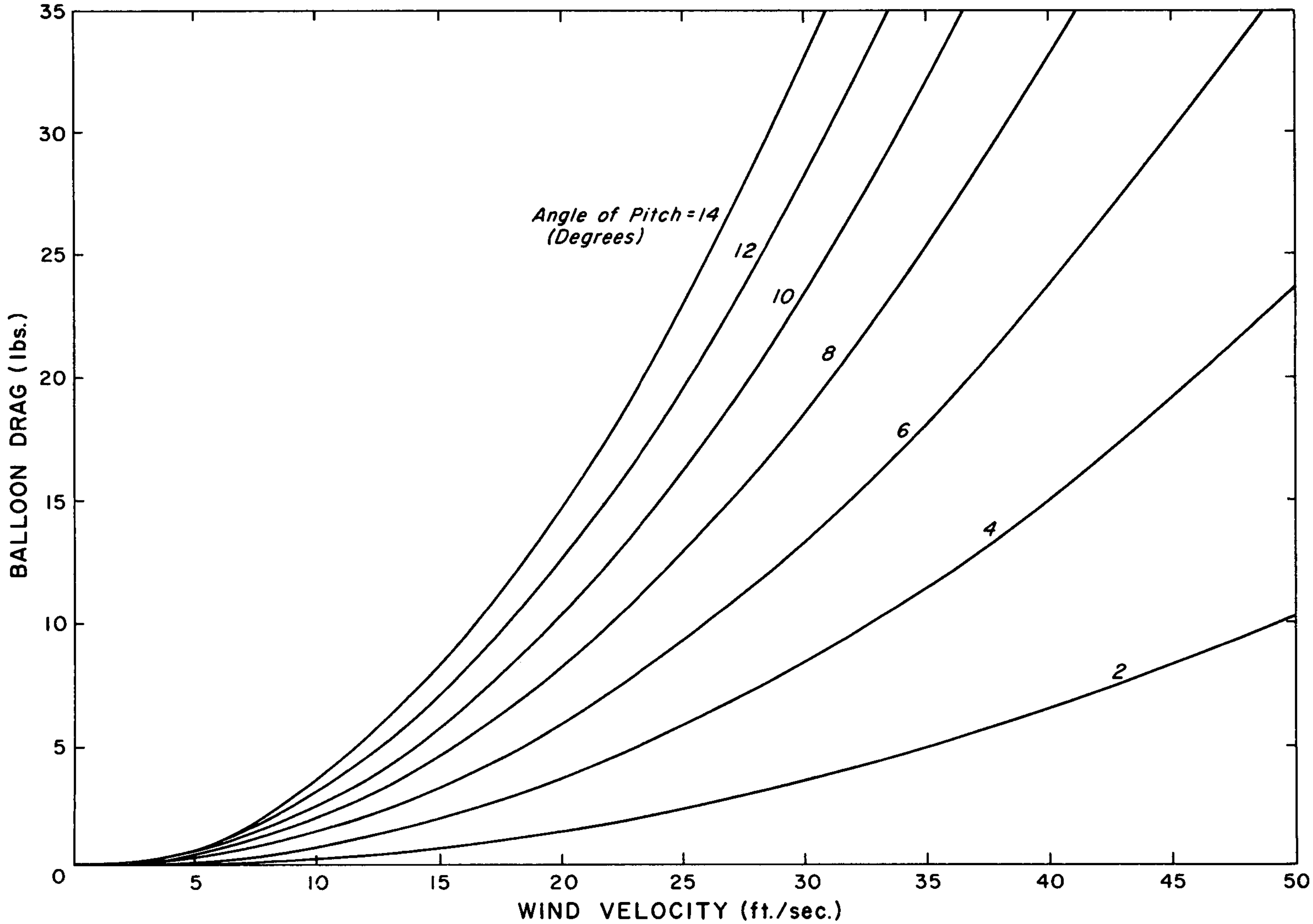
Horizontal and vertical stabilizers were designed. The area required was calculated to be 50 ft^2 (25 ft^2 for the horizontal stabilizers and 25 ft^2 for the vertical stabilizers). A span of 9 feet was used to insure that the majority of the tail surfaces fell outside the wake. The aspect ratio of the stabilizers was 3.24.

Lift and drag curves for the designed balloon were then calculated.



BALLOON DYNAMIC LIFT VS. WIND VELOCITY

FIG. 6



BALLOON DRAG VS. WIND VELOCITY

FIG. 7

Figure 6 is a plot of lift vs. wind velocity for various angles of attack for the balloon. Figure 7 is a plot of balloon drag vs. wind velocity at various angles of attack.

As previously stated, the balloon must be flown at an angle of attack so that additional lift is generated in the presence of a wind. To select the best angle of attack, the lift and drag at various pitch angles were compared. The resultant of these forces act at an angle with the horizontal and affect the forces in the cable; therefore, the cable arrangement was an important factor in selecting the angle of attack at which to fly the balloon. For a tri-tether arrangement calculations indicated that the balloon system would be most stable when flying at an angle of attack of 6°.

Tether System

A tri-tether arrangement, rather than a single or dual one, was selected for the design because it will provide more resistance to the movement of the balloon in any direction. By mounting the payload below the apex of the three tether cables, and then attaching the balloon to a short cable which supports the tri-tether, even greater stabilization is possible. A sketch of this proposed arrangement is shown in Figure 8 (next page).

Since the cables cannot resist compression, it is desirable to have enough balloon lift so that there will always be tension in all the cables in sidewinds as high as 20 knots. As long as the three cables are kept in tension, the apex will remain relatively stable.

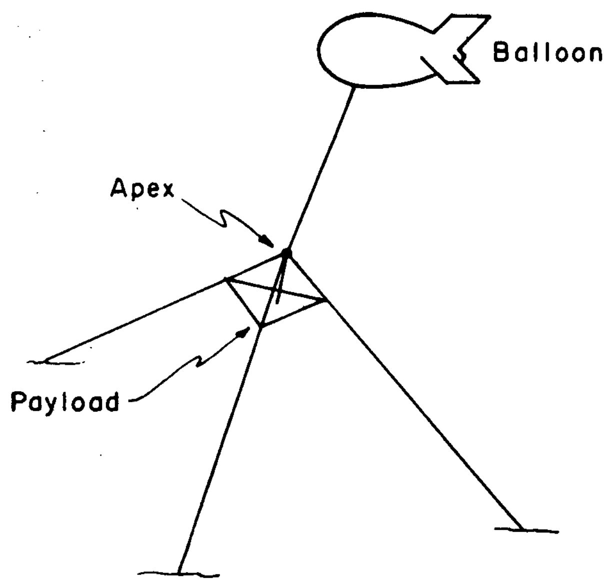


FIG. 8 TRI-TETHER ARRANGEMENT

The tension in each cable is a function of the lift force, the side force, the angle of the side force and the cable arrangement. Calculations were made to determine the tension in each cable for a given lift force while the side force and angle of side force were varied. The results of these studies for an equilateral tri-tether system are given in Figure 9. For simplicity the study neglected the effects of sag and drift. The study reveals that the smaller the angle the cables made with the ground, the greater the side force the system could withstand before becoming unstable. However, as the cable angle is decreased, the cable weight and ground area required for the tethers increases.

The tether system determined to give the greatest stability is one in which two cables are inclined at approximately 47° with the ground while the third is reduced to an angle of 32°. The cable system should be oriented in such a manner that the prevailing wind flows parallel to the longer cable. Assuming an altitude of 200 feet, the total cable length equals approximately 900 feet. The triangular area of ground covered by the tether stakes is approximately 65,000 square feet.

To design the tether lines, the worst possible flight condition was considered. This condition occurs with the balloon at a pitch angle of 90° in maximum winds of 45 ft/sec. Using a factor of safety of 1.5, this results in a minimum breaking strength of the tether lines of 327 lbs.

The major parameters of importance in the selection of the tether lines are the strength-to-weight ratio, the elasticity, and the cable drag. These factors alone may determine the degree of stability of the platform. Based on these considerations, an Al-u-flex swaged winch line made by the American Chain and Cable Company was selected. The specifications of the chosen cable are as follows:

Strand Diameter: .038/.040
Part Number: RA-6643
Minimum Rated Breaking Strength: 380 lbs.
Weight per 1000 ft: 3.85 lbs.

The primary advantages of this cable are its low elasticity to reduce sag and its smooth, low-drag surface. With the tether lines and arrangement designed, the lift and drag on the cables were calculated. The results gave:

Cable lift = -.25 lbf
Cable drag = 1.88 lbf.

At the maximum design velocity of 20 knots, with the balloon flying at an angle of attack of 6° and with the cable arrangement as designed, the total forces at the apex are as follows for a hot windy day:

Balloon Static Lift	=	57.0	lbs.
Balloon Dynamic Lift	=	13.4	lbs.
Cable Lift	=	-0.25	lbs.
Total Lift		70.15	lbs.

Balloon Weight	=	20.0	lbs.
Cable Weight	=	4.0	lbs.
Payload Weight	=	10.0	lbs.
Total Weight		34.0	lbs.

Total Lift	=	70.15	lbs.
Total Weight	=	34.0	lbs.
Excess Lift		36.15	lbs.

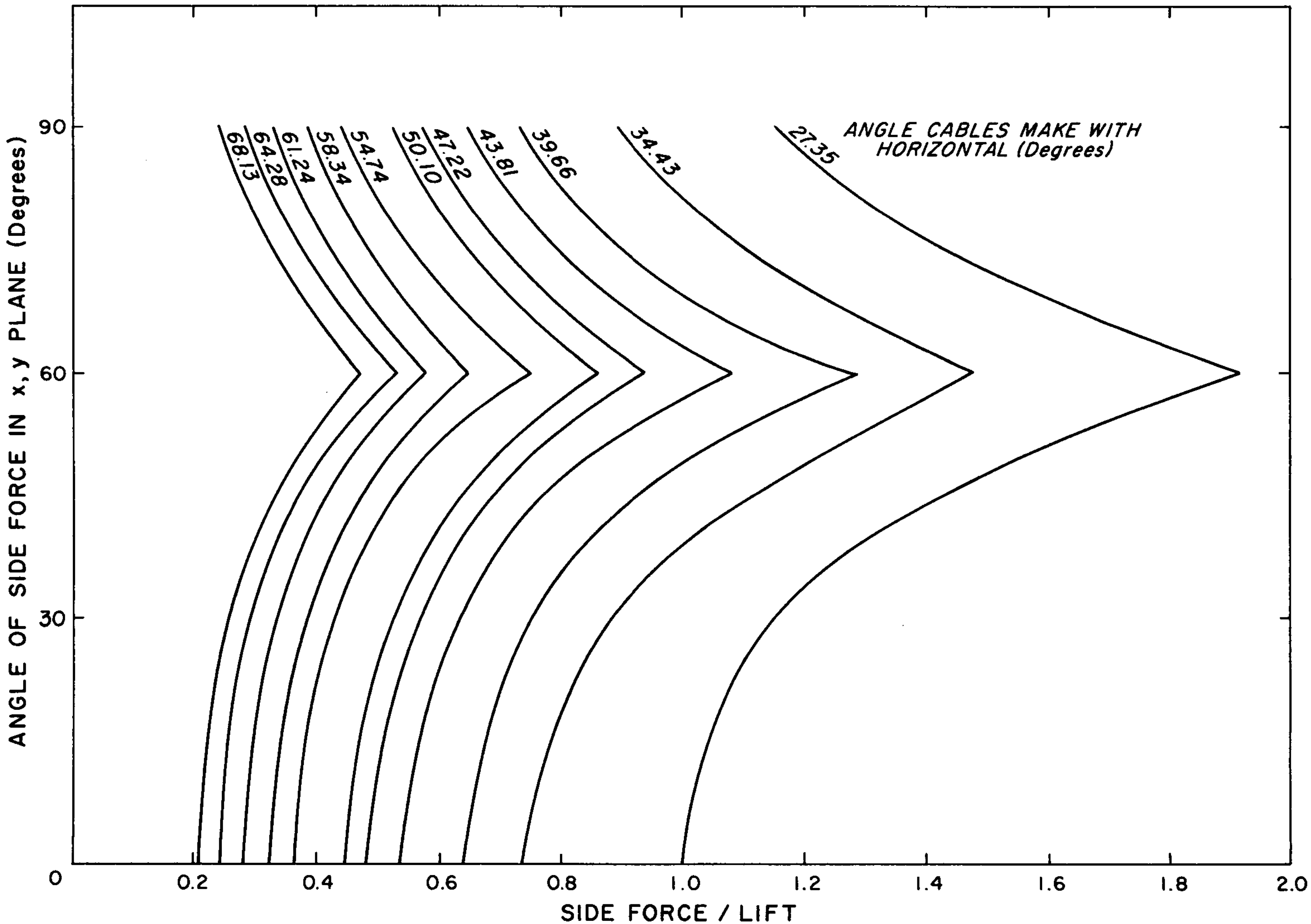
Balloon Drag	=	4.8	lbs.
Cable Drag	=	1.88	lbs.
Total Drag		6.68	lbs.

$$\frac{SF}{L} = \frac{\text{Total Drag}}{\text{Excess Lift}} = \frac{6.68}{36.15} = 0.185$$

Based on curve similar to Figure 9, only for the tether arrangement used, the ratio of side force/lift required to buckle any cable of the proposed system is 1.57. Under maximum design wind conditions as given above, the side force/lift is only 0.185.

In conclusion, the design of a balloon cable system showed that such a system is feasible for use as an elevated stable platform. Although the balloon itself cannot be stabilized, a properly designed cable system combined with an aerodynamically shaped balloon can provide a stable platform for scientific applications. An important factor which was not considered in the calculation is sag. As the tension in the cables increases and decreases, the amount of sag in the lines will in turn decrease and increase. Hopefully, the light weight, low elasticity cable selected will result in a minimum of sag.

Further study showed that the stability of the platform could be



SIDE FORCE/LIFT REQUIRED FOR BUCKLING ANY CABLE OF AN EQUILATERAL TRI-TETHER SYSTEM

FIG. 9

improved considerably if it were cabled to the ground rather than connected to the three primary cables as shown in Figure 10. Adding three additional cables for this purpose would increase the weight by less than three pounds and the drag by only two pounds. In addition, a rigid connection could be used to join the payload to the apex of the primary cables. With a ball and socket joint located at this connection, the apex could move slightly without movement of the platform.

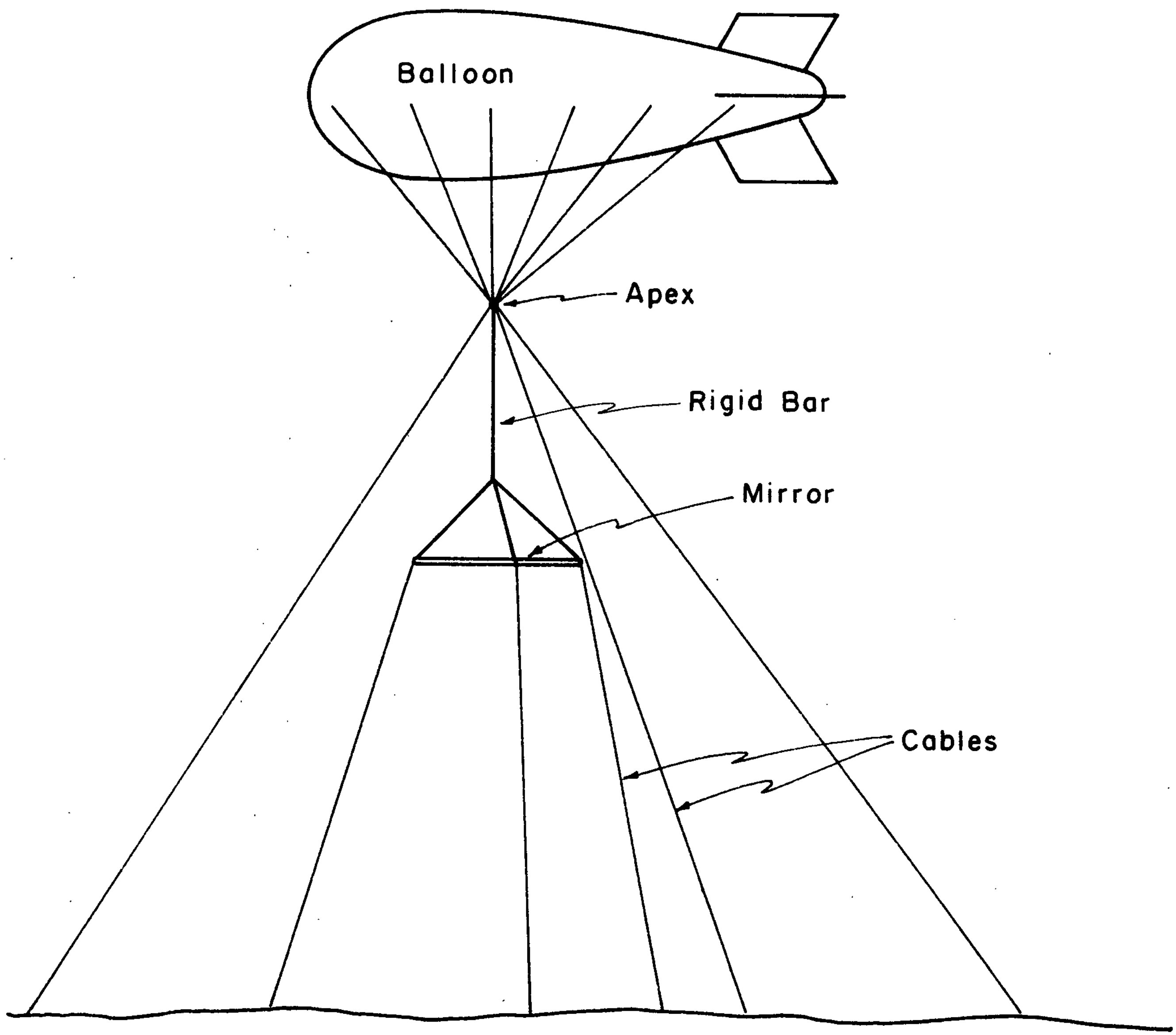
Purchased System

Even though the balloon design as discussed was not shown to be absolutely stable, it was decided that the possibility was great that such a system would work. Therefore, we began looking into the problems involved in building a balloon system as designed. It was quickly learned that building a balloon would be both costly and time consuming. Consequently, a review was made of all balloons with a volume of 1000 to 1500 cubic feet that could easily be purchased.

The balloons which appeared to conform the closest to the one designed earlier were those manufactured by the Robert Fulton Company. Therefore, a 1200 cubic foot balloon (Model No. BUED-12-1) was ordered from that company. A larger balloon than the one designed was ordered since the payload weight after the mirror system design was finalized increased to 12 pounds. The only other size balloon manufactured by the Robert Fulton Company had a 725 cubic foot capacity.

It was also decided to use a tri-tether cable system for both the balloon and the mirror. This results in an increase of three pounds in the cable weight; however, the additional cables are considered necessary to help increase the stability as well as help in the positioning of the mirror. A schematic of the proposed balloon system is shown in Figure 10.

The mirror measures four feet by four feet and is made of Mirror-lite which is a polyester film vacuum-coated with aluminum and stretched over a lightweight backing. Its reflective is better than .90 throughout the wavelength range of interest. The mirror itself is made of four panels two feet by two feet, each weighing approximately 1½ pounds. The panels are mounted on an aluminum frame which gives rigidity to the mirror. The cables are mounted to the aluminum frame as is the rigid bar used between the apex of the balloon and the mirror. A ball and socket joint is used on both ends of the rigid bar which extends between the balloon's apex and the mirror.



SCHEMATIC OF BALLOON CABLE ARRANGEMENT

FIG. 10

EXPECTED RESULTS

Although the balloon has been ordered, it had not yet arrived at the university at the time of this writing. Therefore, the proposed experiments are not expected to begin until sometime this summer. At that time the balloon system will have been built so that measurements of the intensity of electromagnetic energy from a field under conditions of natural illumination can be made.

The purpose of the experiment is to determine the variations in the reflectance and emittance with changes in the natural environment. The results of the field test will be used to find correlation factors from the spectral data. Primary variables to be studied are sun angle, reading angle, resolution, moisture content, and atmospheric conditions. From the data collected from the field test, the effects of each individual variable on the spectral data can hopefully be obtained. Example curves of the type of data expected to result are shown in Figure 11. From these curves, relationships can be programmed to help in automatically processing raw data obtained by remote sensing techniques.

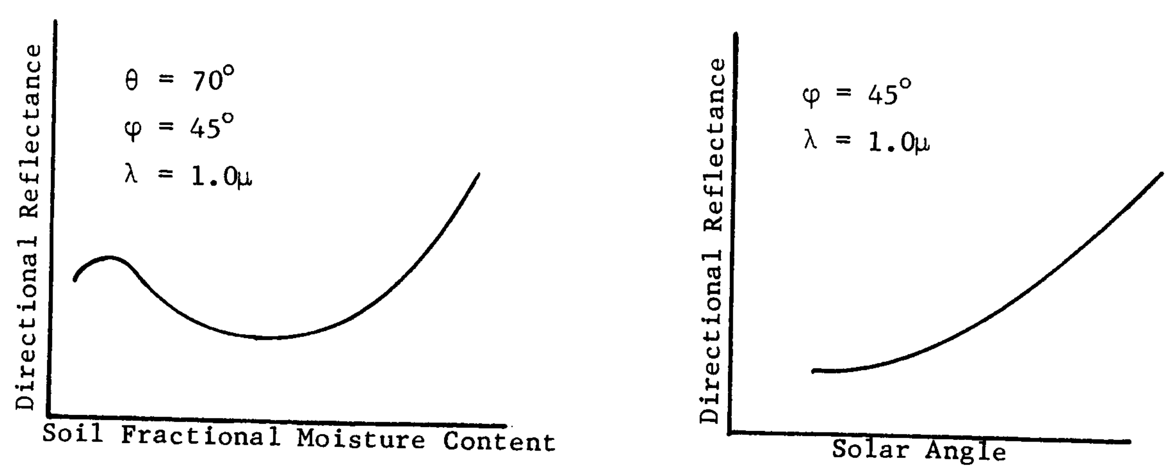


Figure 11. Sample of Expected Results

CONCLUSION AND SUMMARY

Regardless of the type of technique used in remote sensing, in order to automate the interpretation process and to identify things such as plant and soil types, more information is needed on the effects of the natural variables involved as well as the variables introduced by the system used. Until this type of information is obtained and understood, remote sensing as a technique for inventorying our natural environment will be slow and limited and will require extensive ground truth measurements to check the results.

In order to help solve the difficulties mentioned and to add to the generation of data needed in finding ways to simplify interpretation of remote sensing data, an experiment was outlined and the required equipment built or purchased. The equipment consists of a balloon system (which acts as a stable platform to hold a mirror aloof) and a mobile remote sensing laboratory. The mobile remote sensing laboratory is a type of radiometer mounted on a turret mechanism. The laboratory is designed for field work, is self-sufficient, and can be totally stored on a truck.

The radiometer consists of a telescope with all lenses removed and replaced by mirrors which focus the received radiation into a monochromator. The radiation from the monochromator is focused onto detectors which measure the intensity of the electromagnetic energy as a function of wavelength. Measurements from a wavelength of 0.2μ to 15μ can be obtained with the system.

A large mirror is stationed in the sky which folds the energy emitted or reflected by vegetation on the ground back to the mobile remote sensing laboratory. The stability of the balloon system for holding the mirror is still somewhat in question since the balloon has not yet arrived; however, an analytical study was made which resulted in a unique cable arrangement which promises good results.

Tests on the stability of the balloon system are expected to be made this spring. If successful, the generation of data from the remote sensing experiment will begin in the summer. If the balloon system proves infeasible, the mobile remote sensing laboratory will be used from a tall building or an existing tower. However, this type of arrangement will not allow the versatility of a balloon holding a mirror aloof.